
Value Focused Thinking and Probabilistic Reasoning for Space Mission Design

Gordon Research Conference on Theoretical Foundations For Product Design & Manufacturing

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NASA
Space
Exploration

Mission Value Model

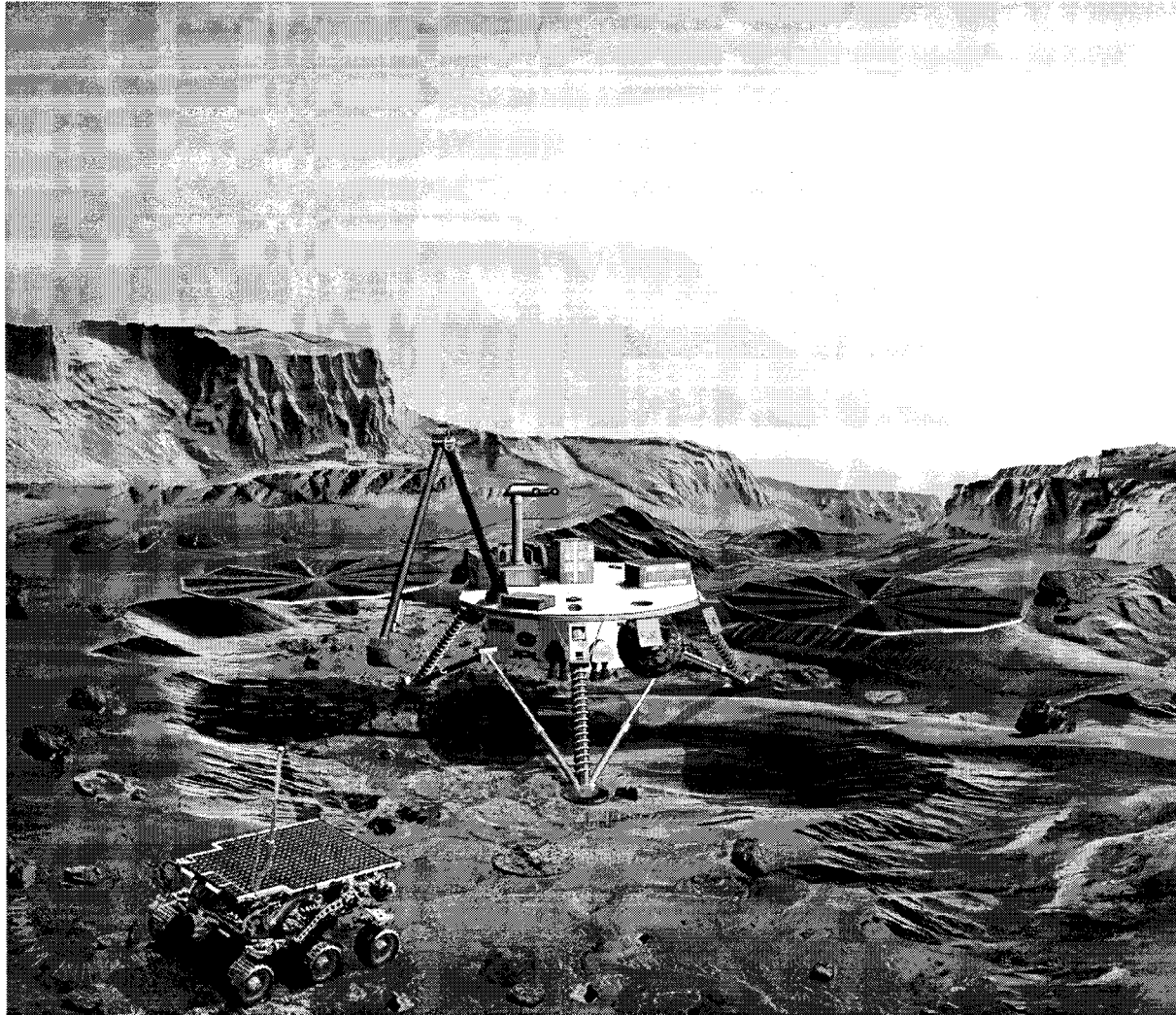
- Science
- Technology
- Military
- Education
- Public Relations
- Outreach
- Cost
- Resources (other than cost)
- National Prestige
- Survival of Humanity
- Survival of the Environment

Origin
And
Evolution of
Life

Origin
And
Evolution of
The Solar System

Origin
And
Evolution of
The Universe

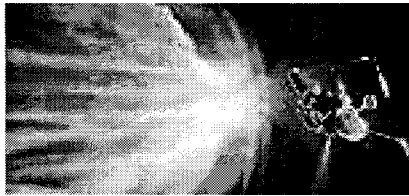
Mars Lander and Rover



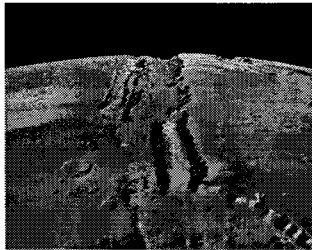
The Big Picture

**Target Science
Models**

MORE DATA



Comet

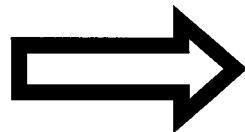
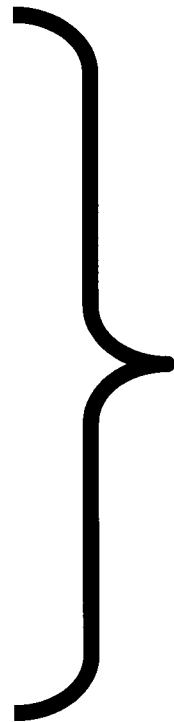


Mars



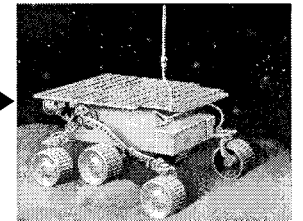
Earth

JPL



**Synthetic
Environments**

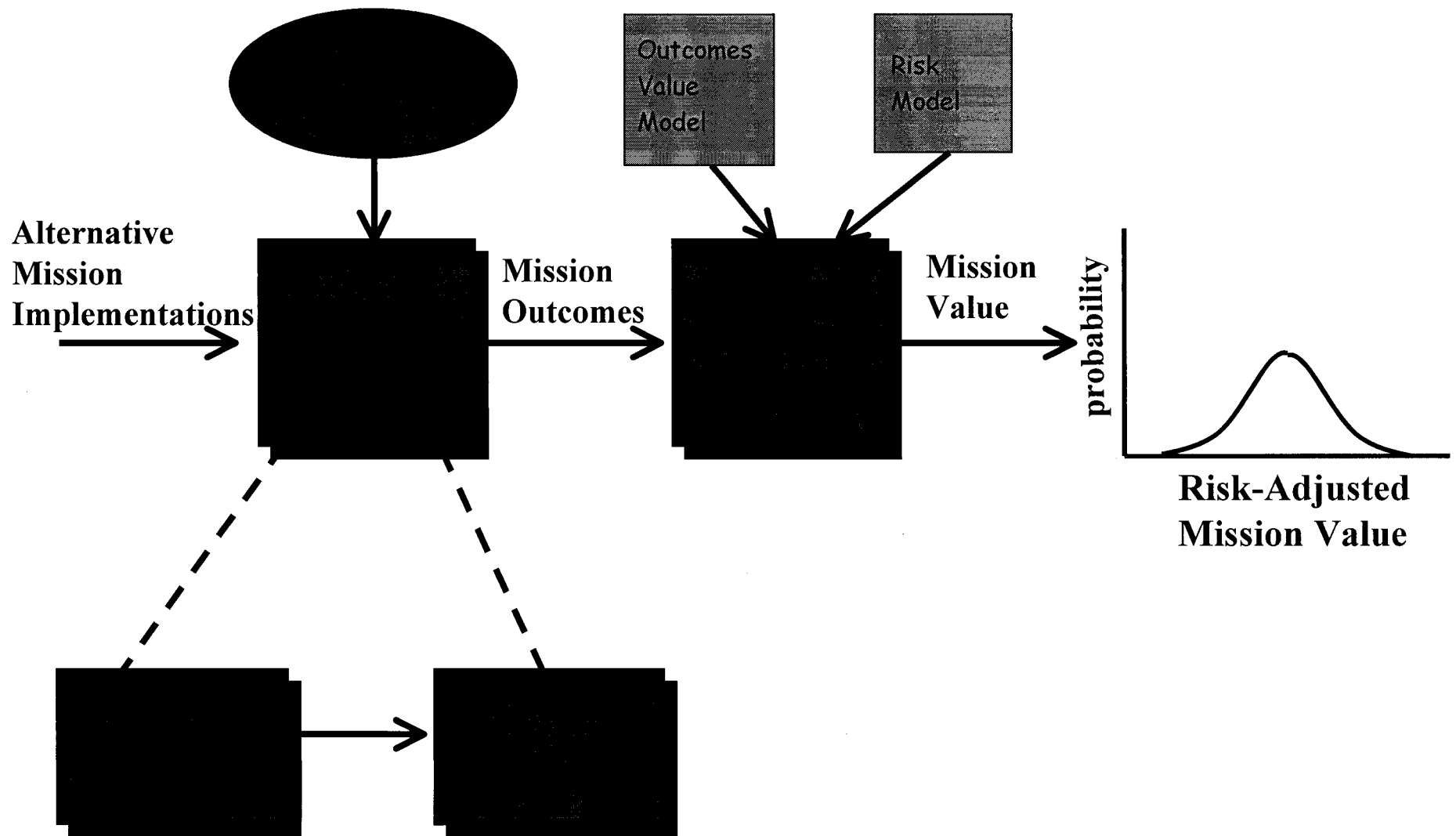
Mission



**Virtual
Prototypes**



Value Focused Thinking & Probabilistic Reasoning for Space Mission Design

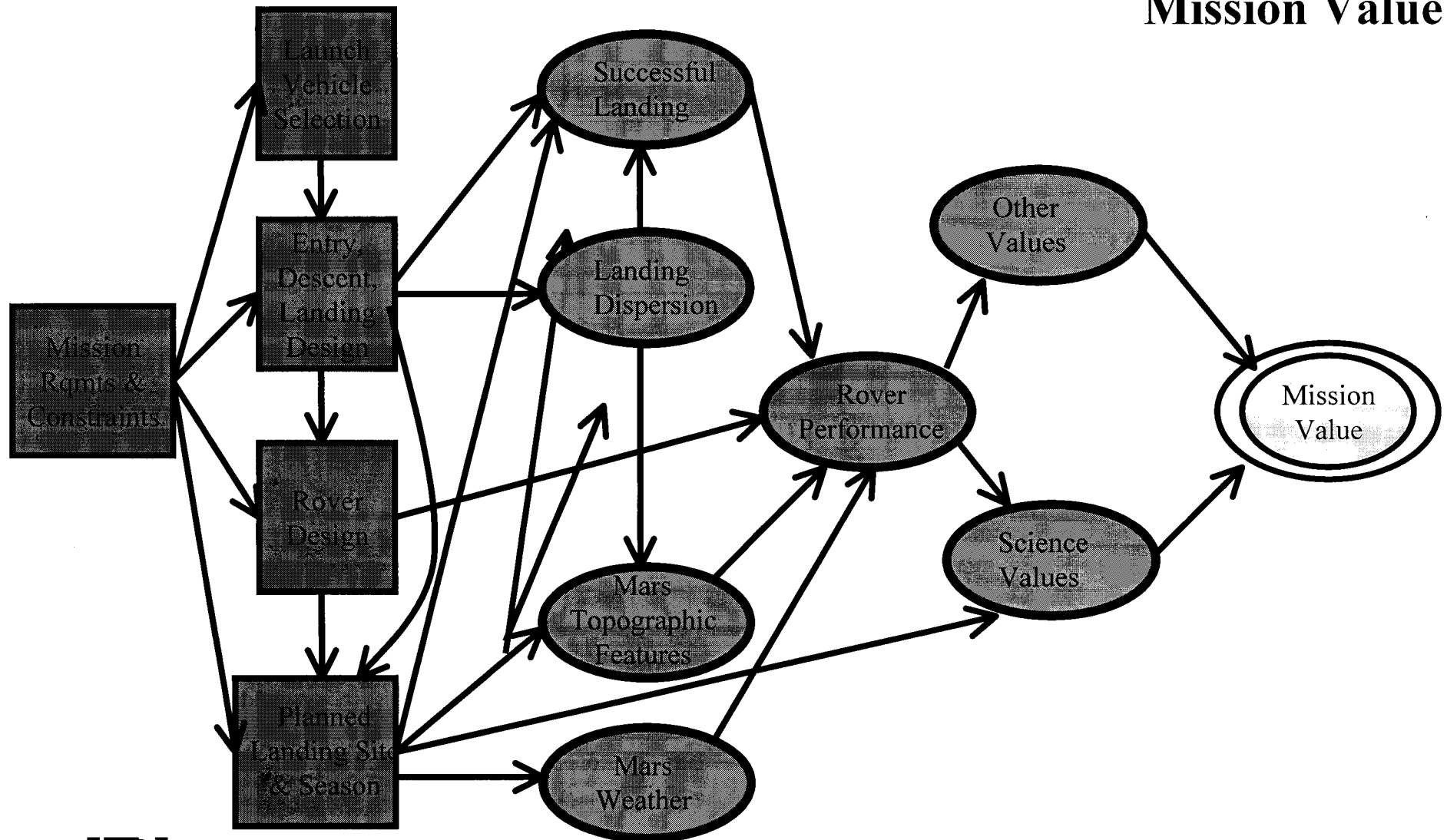


Influence Diagram for Mars Surface Exploration

Decisions

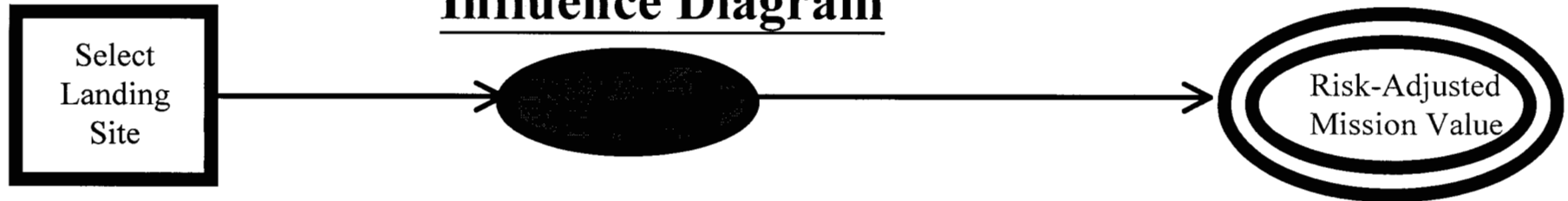
Uncertainty

**Risk-Adjusted
Mission Value**

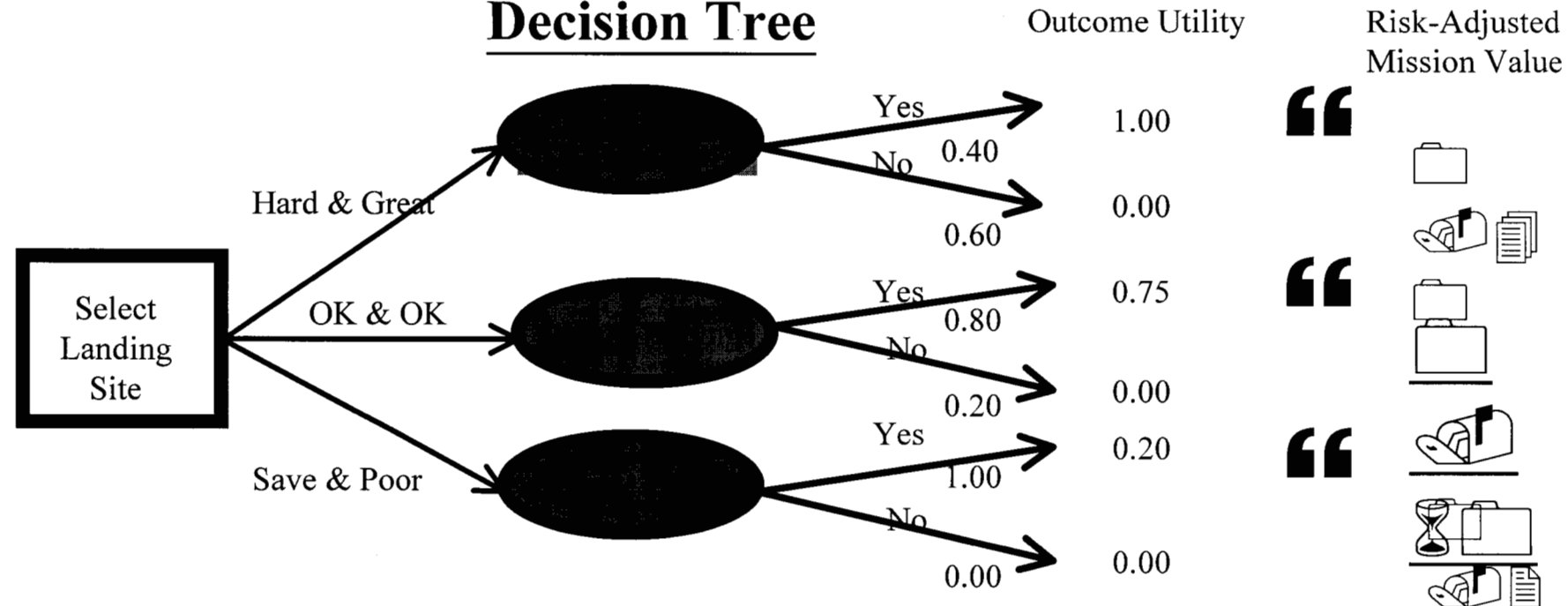


Value-Focused Thinking and Probabilistic Reasoning For Landing Site

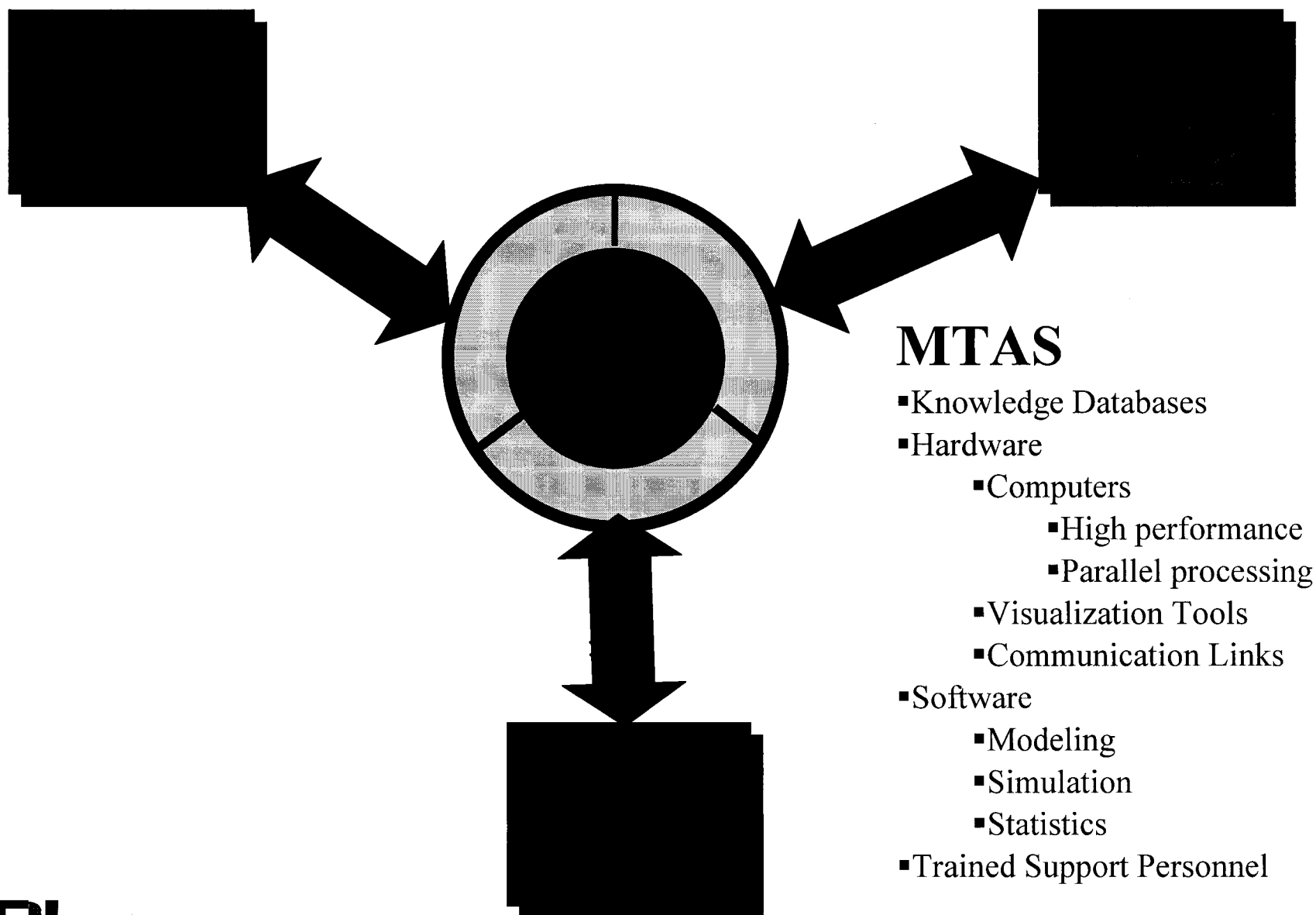
Influence Diagram



Decision Tree

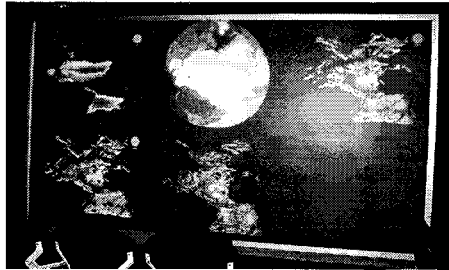


Mission/Technology Analysis and Synthesis Center



High Performance Computing and Communications

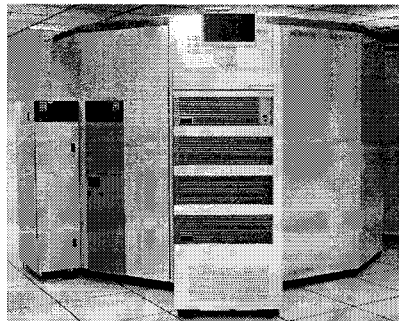
JPL Assets



PowerWall

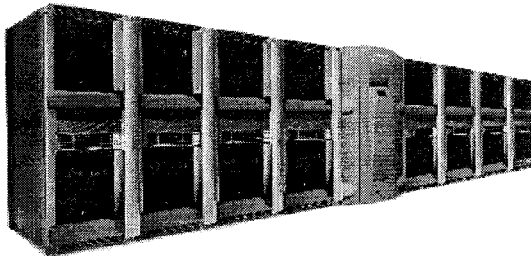
- 6 Electrohome DLV 1280
- 1 Digital Projection 6SX
- 7.8 MegaPixel Display

To NTON



Storage Tek Silo

- 6000 tape capacity
- 50 Gigabytes per cartridge
- 1000 cartridges currently in silo
- Maximum capacity: 300 Terabytes



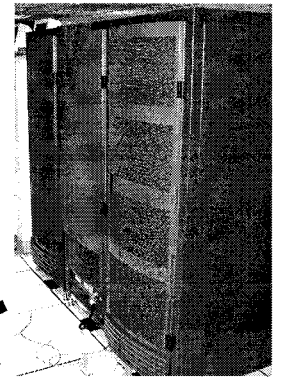
SGI Origin 2000 Reality Monster

- 128 CPU Parallel Processor
- 600 MFLOPs/cpu
- 32 Gigabyte main memory
- 2.2 Terabyte Disk

SGI SVT-A

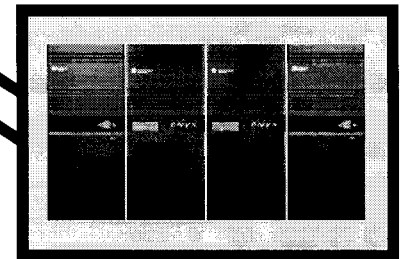
- 16 CPU Parallel vector Processor
- 1000 MFLOPs/cpu
- 8 Gigabyte Memory
- 480 Gigabyte Disk

To JPL Auditorium



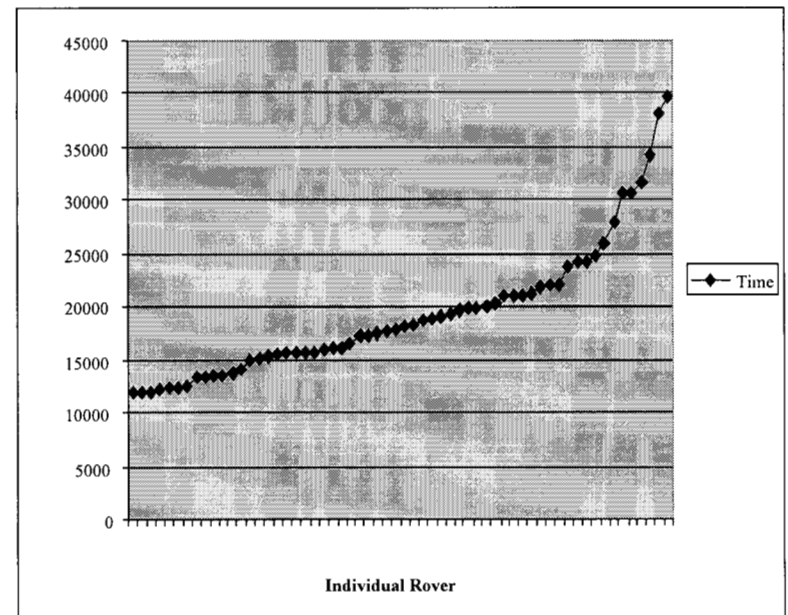
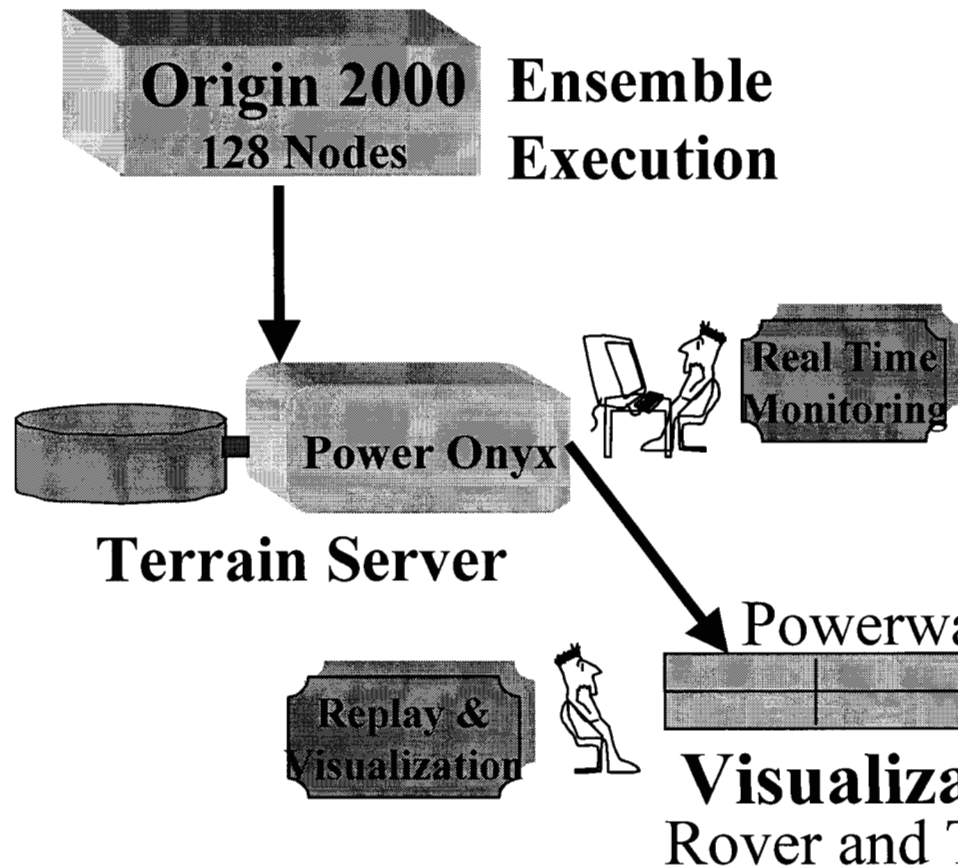
SGI Dual Power Onyx

- 12 CPU processor
- 500 MFLOPs/cpu
- 4 Gigabyte main memory
- 512 Gigabyte Disk



High Performance Terrain Generation, Rover Simulation, and Visualization

Terrain Generation



Analysis:
Statistical and Risk

Creating the Virtual Environment and Simulation Model Is the Hard Part.....

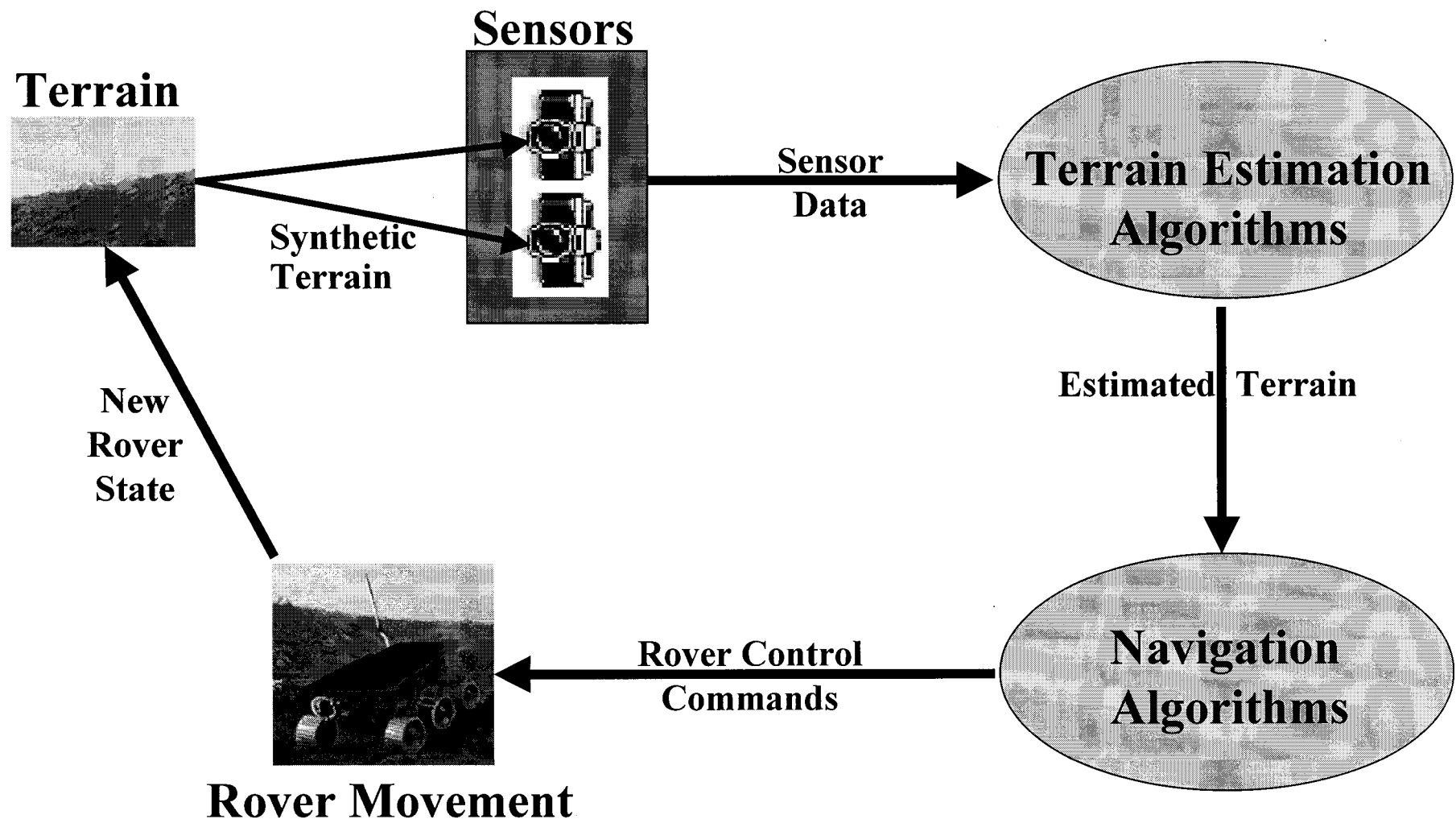
- But It's Not Enough!
- To Be Effective These Modules Should Be Embedded in an 'Ensemble' Simulation Environment.

For:

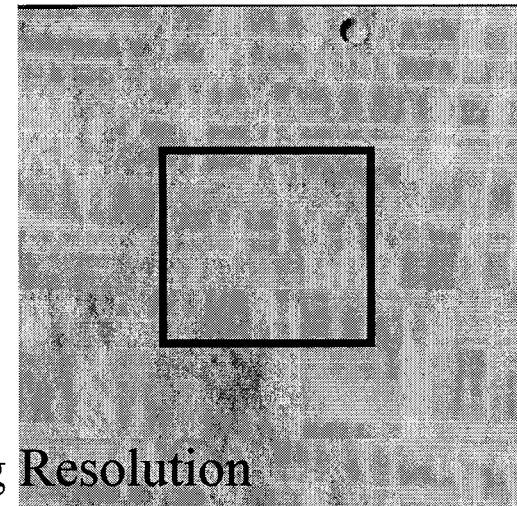
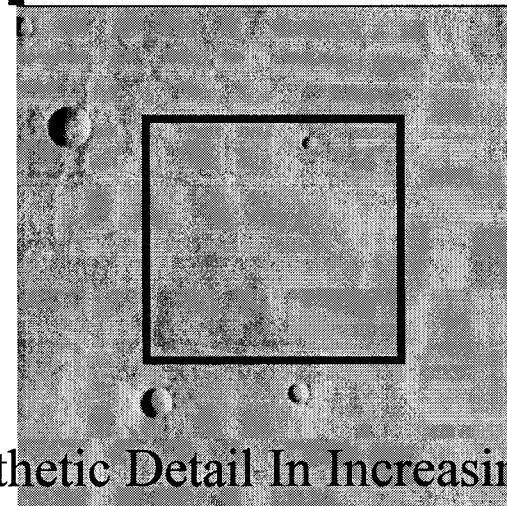
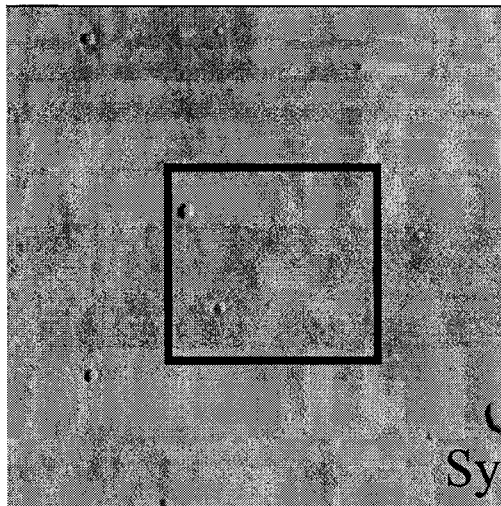
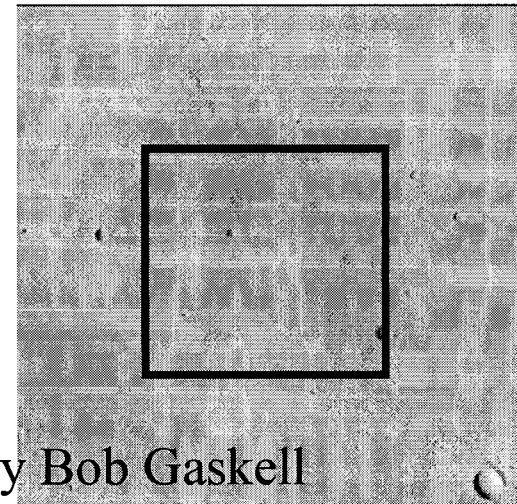
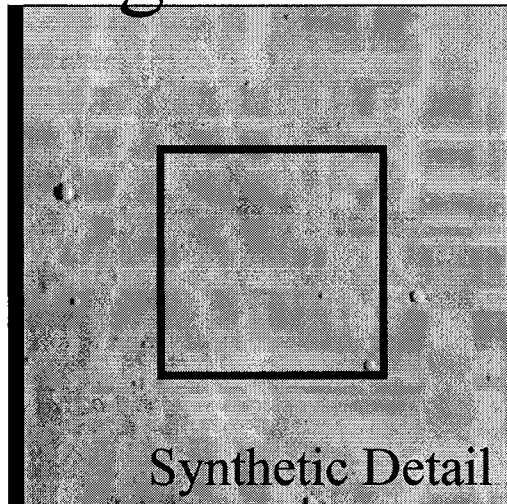
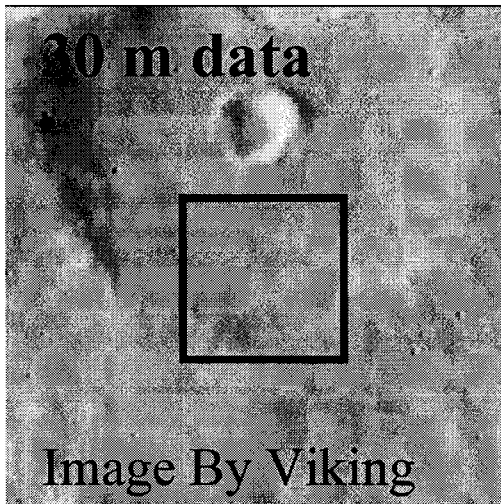
- Rapid Design Space Exploration
- Formal Cost/Risk Analyses
- Mission Replan During Operations



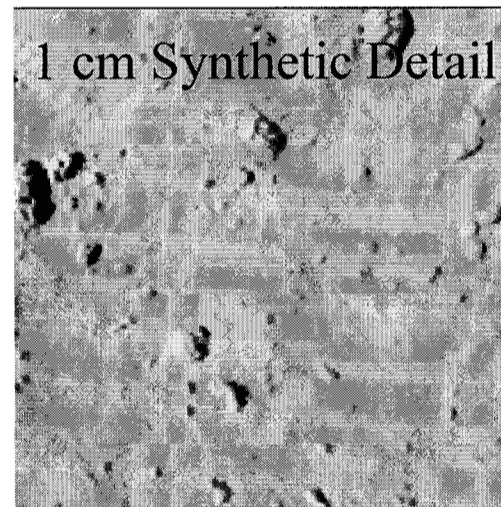
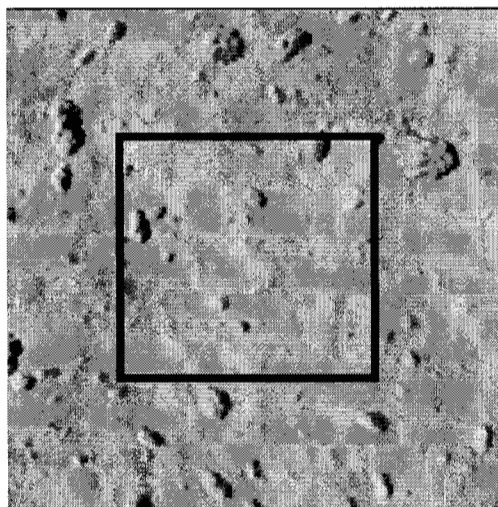
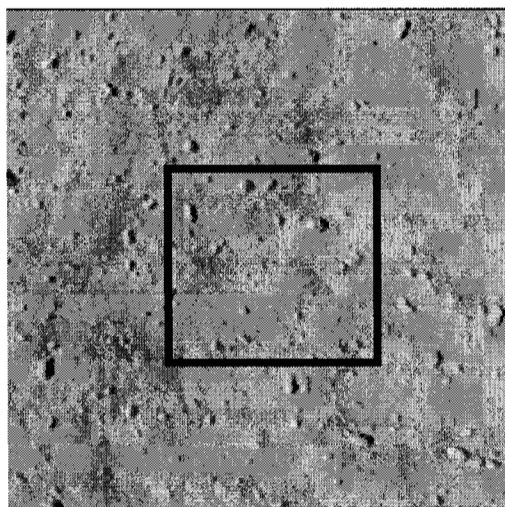
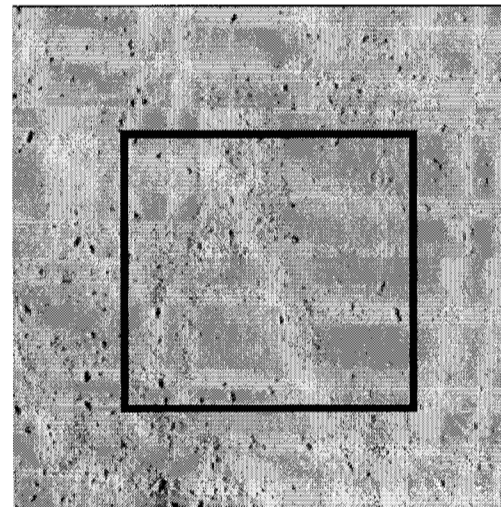
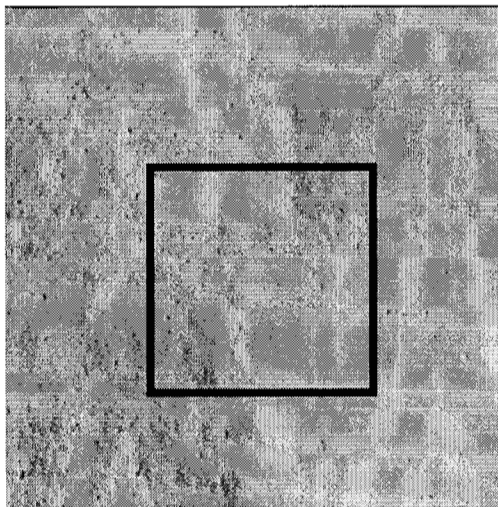
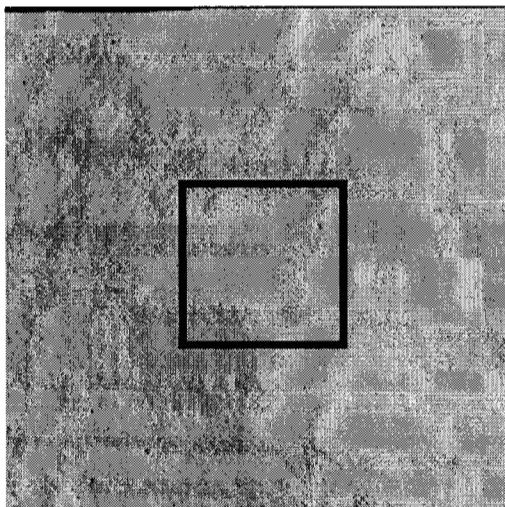
Basic Rover Simulator



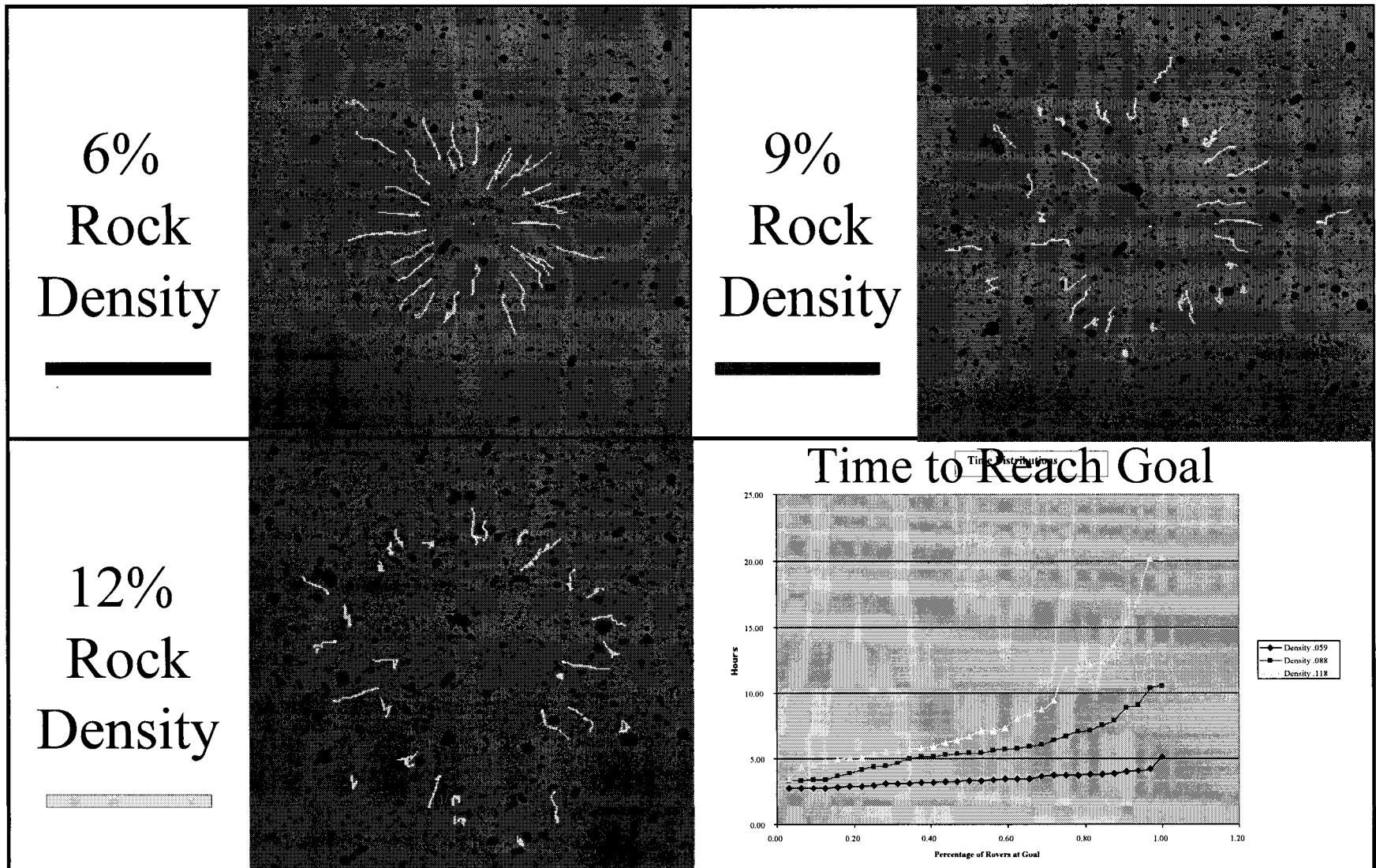
Terrain - Starting With What We Know & Filling in the Details



More Detail

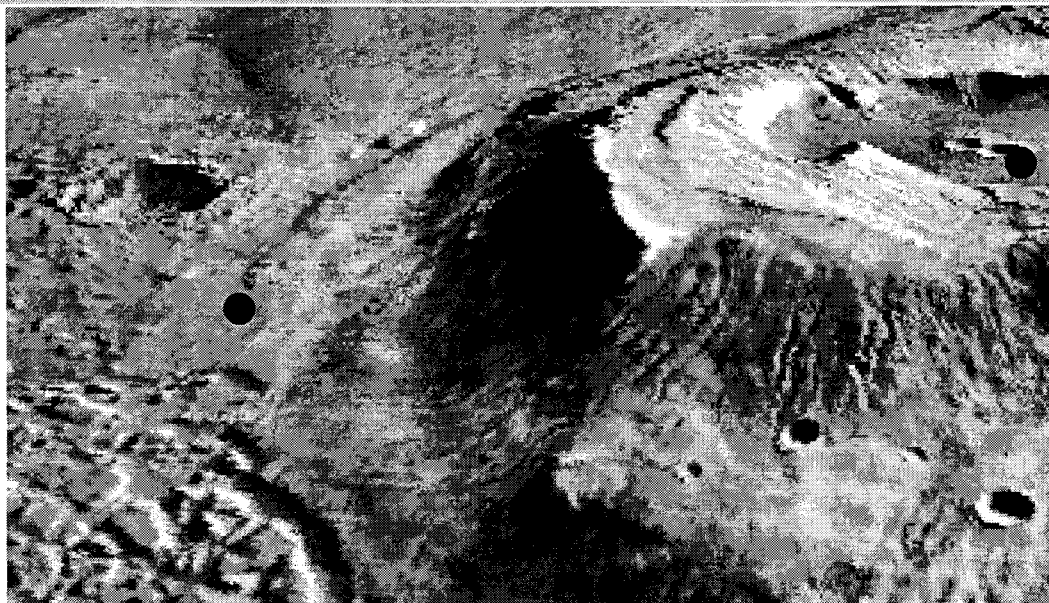


Rovers at Three Rock Densities

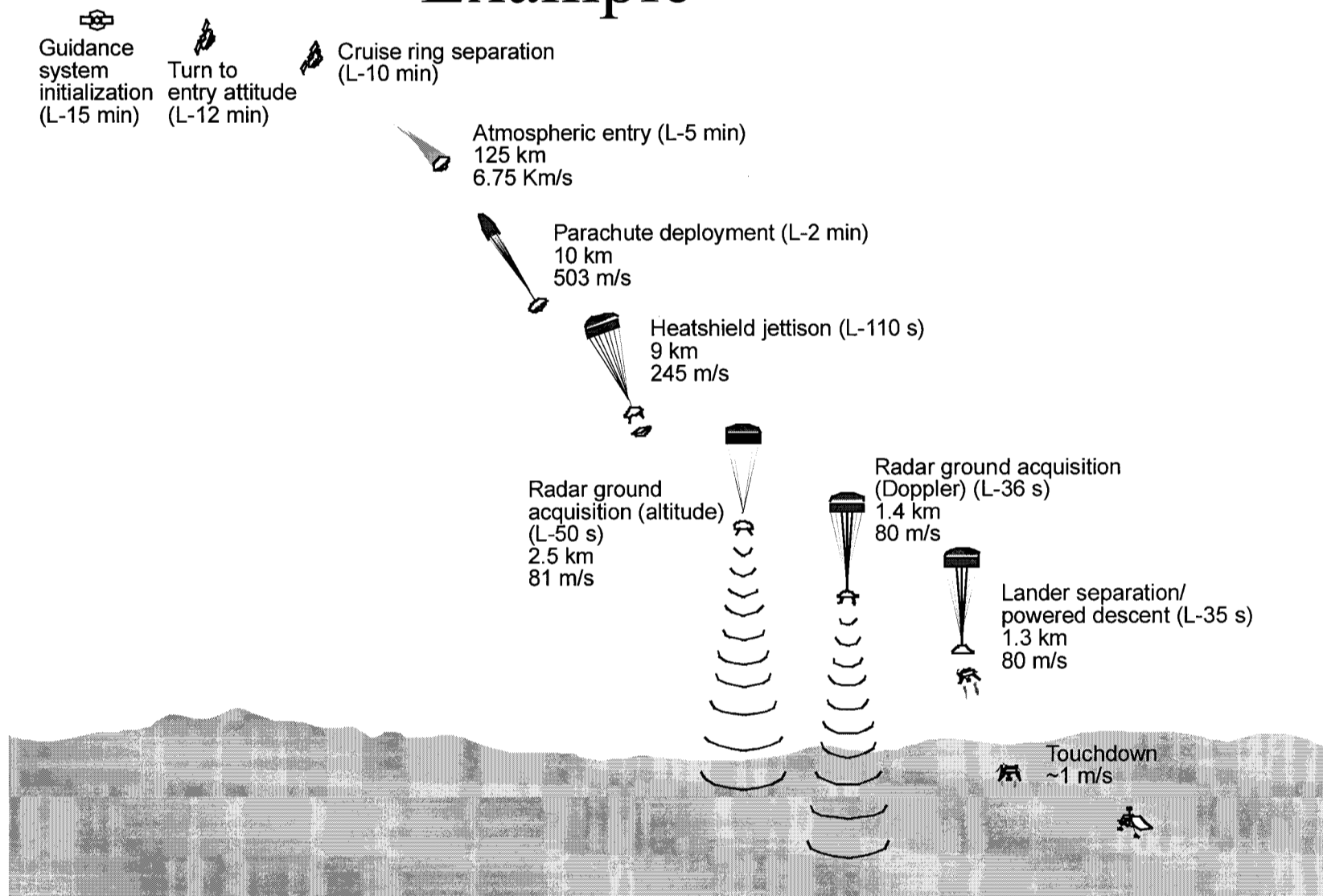


Proposed '01 Landing Site – Apollinaris

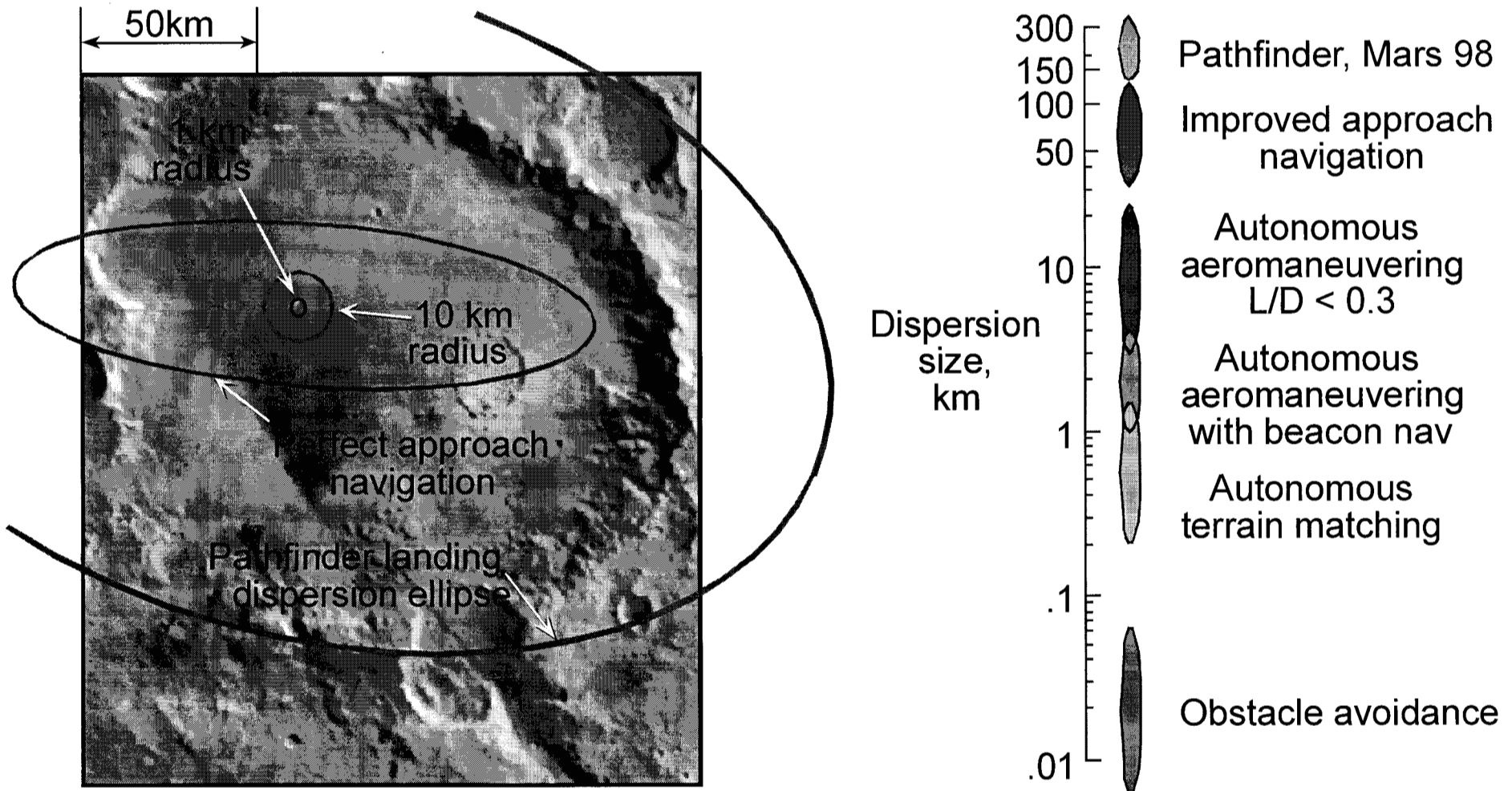
Patera 3 <http://marsoweb.nas.nasa.gov/landingsites/sites.html>



Entry Descent Landing - A Second Example

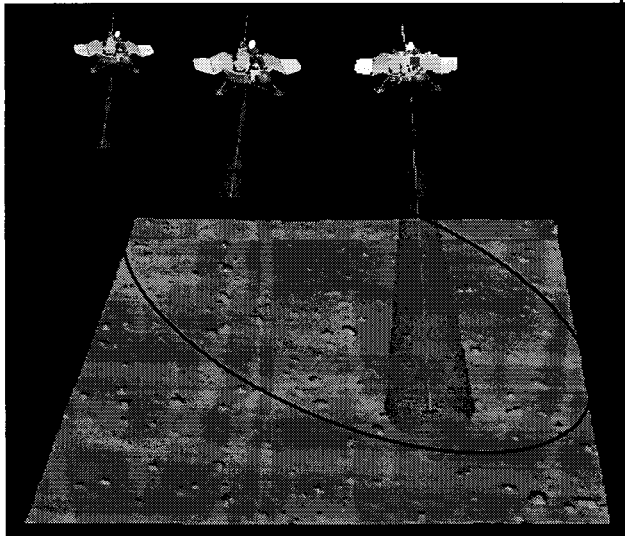


The EDL Architecture Problem

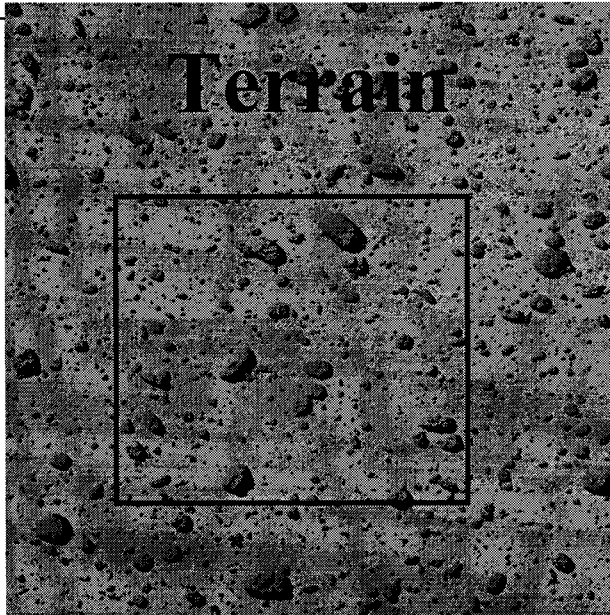


An Ensemble EDL Simulation - Keeping Track

The Ensemble

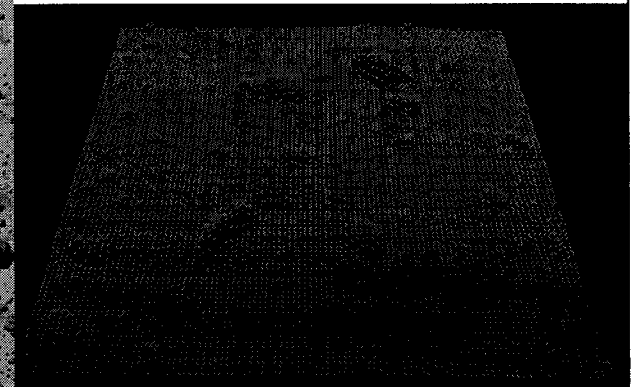


Terrain



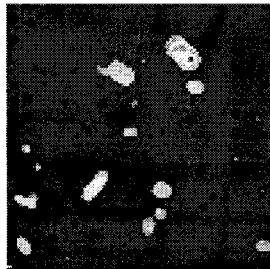
Lidar Data

(for red bordered terrain region)



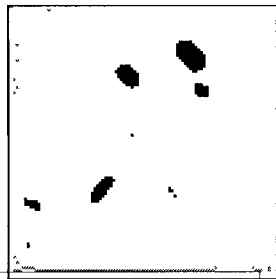
Terrain Estimate

(from Lidar Data)



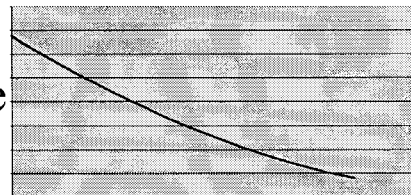
Hazard Map

(from Terrain Estimate)

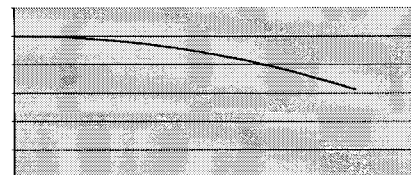


Guidance

Altitude



Fuel



Hazards



Time

Monte Carlo Statistics

% Landed



% Safe Landings



% Within Target Zone



Avg Fuel Reserves



A New Paradigm for System Validation

Validation - Ensuring that the system will work as required

- The old paradigm.
 - Tests validate the system.
- The new paradigm.
 - Tests validate the simulation.
 - The simulation validates the system.
- Example #1 - Validating Pathfinder Descent.
 - Parachute, backshell, bridle, and lander tested at China Lake.
 - System simulation replicated the China Lake results.
 - Simulation using the projected Mars environment validated the flight system.
- Example #2 - Similarly, the Mars Yard can validate Mars Rover simulations under both obstacle and lighting conditions.

Why A New Paradigm?

- The system simulation may be a better validation than any system test.
- The system simulation may be more cost-effective and resource-conserving than any system test.
- The capability is now emerging for rapid & comprehensive system simulation.
 - The facilities (computers and visualization tools), software, and simulation talent are now developing.

Summary

- General circulation between science knowledge databases, synthetic environments, and simulation models is the key to future mission design.
- Modeling itself is hard part, but ensemble simulation is a must for many problems. Need lots of trials.
- All the simulations must be validated against realistic tests.
- The emerging supercomputer facility with value-focused thinking and probabilistic reasoning will result in better space missions, designed both faster and cheaper.